LCA Methodology

Waste Treatment in Product Specific Life Cycle Inventories

An Approach of Material-Related Modelling

Part I: Incineration
Part II: Landfilling (Int. J. LCA 3 (2) 1998)

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Abstract

In product specific Life Cycle Assessment the environmental impacts resulting from the disposal of the product under study frequently have a strong influence on the overall result. Since the major disposal system – the Municipal Solid Waste Incineration (MSWI) and the Sanitary Landfill (SL) – are complex processes specially adapted for the treatment of a large variety of different types of waste with varying input composition, the direct determination of the environmental impacts coming from a single input component for example by measurements is not practicable. Two methods (Part I: MSWI, Part II: SL) of allocating the inventory positions caused by the processes MSWI and SL to individual input fractions are presented. The approaches described are based on process modelling for the calculation of the material and energy inputs and outputs of the disposal systems. For the MSWI process the material related allocation is carried out by means of a study of difference: The input/output balance is calculated with the process model for two variants with different input compositions. The input for the first variant consists of waste of average composition enlarged by a small amount of special waste fraction under study. In the second variant the calculation is done with an input consisting only of waste with average composition. The difference formed between the results of process calculation for both variants gives the effects of the treatment of the waste fraction under study in the disposal process.

Keywords: LCA, waste disposal, incineration; landfill, waste, LCA; material-related modelling, waste incineration; municipal solid waste incineration, LCA; waste disposal, material-related modelling, LCA; waste incineration, material-related modelling, LCA

1 Introduction

A Life Cycle Inventory (LCI) contains all activities and processes involved in manufacturing and using a product or a service. The life cycle starts with the extraction of the raw material from the earth, includes the refining, the production and the use of the product and ends with waste disposal. This last part of the system deals with the post-use phase of the object under study. All parts of the used product which are not reused or recycled and also the waste generated in the processes connected to the life cycle have to be treated in waste disposal systems. The two major systems to handle the waste – as long as it is not classified as hazardous waste according to specific stipulations – are the waste incineration and the sanitary landfill.

In the preparation of product Life Cycle Inventories, we are confronted by two facts in the field of waste technology:

- Frequently the environmental impacts resulting from disposal of the product under study at the end of the product life have a considerable effect on the overall result.
- The treatment and disposal of the products under study as post-consumer waste, takes place together with that of a large amount of other waste in complex processes with varying input composition.

Processes whose input or output includes more than the material flow to be studied occur at many places in the lifetime of a product. The allotment of the environmental impacts caused by these processes to the material flows to be studied takes place via more or less cause-related allocation rules. In the field of waste disposal processes, the application of "simple" rules of allocation (for example allocation of resource consumption and emissions to individual waste fractions proportional to mass or calorific values) often leads to nonsensical partial results with a considerable effect on the overall result (for example the allocation of SO_2 emissions from waste incineration to sulphur-free input fractions etc.).

In the past, many studies therefore excluded waste treatment and only indicated the use of waste treatment capacities ("kg to incineration" or "m^3 of occupied landfill space").

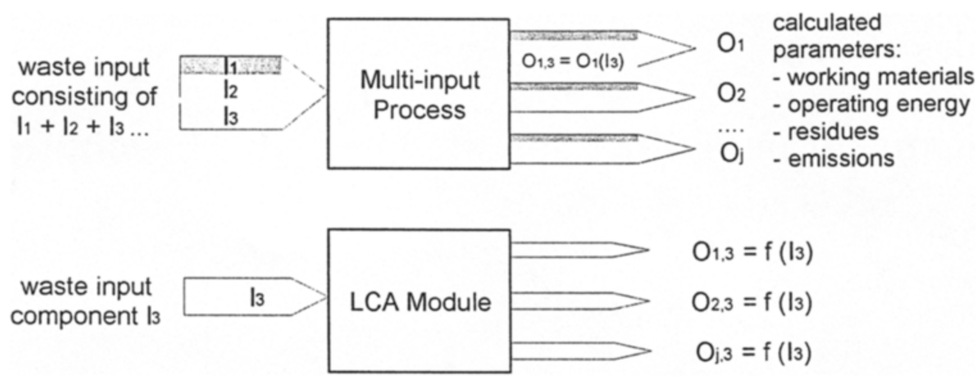

Fig. 1: Multi-input process and allocation of output parameters to individual input components

In the following we shall describe 2 methods (Part I : Incineration, Part II: Sanitary Landfill) of allocating, in a way which is as cause-related as possible, the inventory positions caused by the processes Municipal Solid Waste Incineration (MSWI) and Sanitary Landfill (SL) to individual input fractions.

Both approaches simplify and start from a mixed standard waste input (→ *Fig. 1*) which has the material flow under study (I_3 in *Fig. 1*) as a component. This standard input is projected onto the other input values and the output values of the waste treatment process (other inputs and outputs: $O_j = O_1, O_2, ...$) via calculation rules and as a function of operating parameters. The input and output values include residues, individual emissions and secondary raw materials as well as the consumption of working materials and the use of operating energy. These calculation rules, which in the most simple case consist of mass balances with empirical distribution coefficients, allow us to calculate which share $O_{j,i}$ of the inventory position O_j must be allotted to the input fraction I_i.

The derivation of reliable functions $O_{j,i}$ (I_i) = f (mass and composition of I_i) is difficult when the basic physical-chemical correlations are not sufficiently well-known or the value O_j involved does not depend on the composition of the input. In these cases, plausible stipulations must be made in a transparent way in modelling.

To derive the above mentioned functions $O_{j,i}$ (I_i) for the waste incineration process, the process has to be calculated by the aid of an input-based process model. Input-based process models of waste management processes are known from former publications [1,2]. In these approaches, the input and output flows connected to the incineration of a defined input composition are determined on the basis of a stoichiometric combustion calculation together with empirical process data. The results give a more or less complete input/output balance of the incineration process. These methods aimed at calculating the waste combustion process for average waste mixtures, an allocation of the input/output flows to single input materials, however, was not carried out.

2 Methodological Approach

The approach described here is also based on process modelling for the calculation of the material and energy inputs and outputs of an incineration system. A direct calculation of the multi-input system for a single input component is feasible if the relationship between the incoming material and the output values of the process calculation can be described by linear equations. If there are non linear correlation occurring in the process model like for example internal recycling flows, such a direct calculation of the multi-input

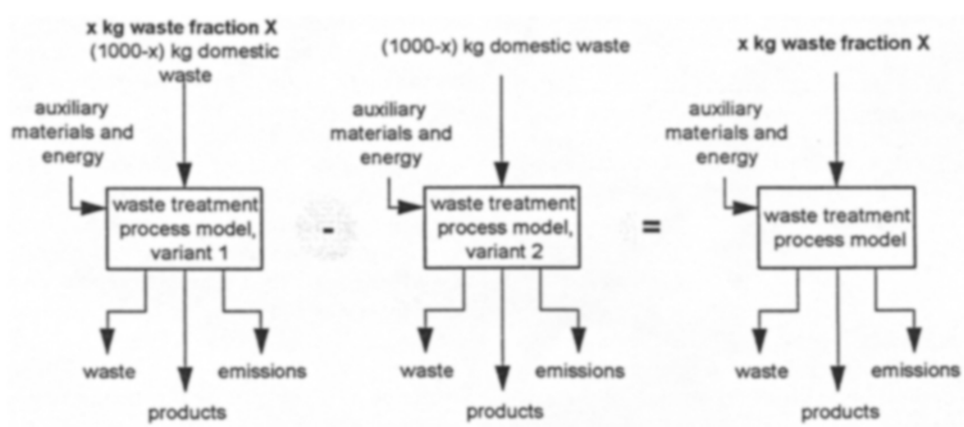

Fig. 2: Allocation of the input/output flows of a multi-input system to a single waste fraction

process for single components could lead to improper results. In this case the results of the process calculation do not only depend on the condition and composition of the single input component under investigation but also on the question which portion the special component takes of the total input of the multi-input process.

Figure 2 shows the principal approach for the allocation of the input and output flows resulting from the treatment of waste in a multi-input disposal system to a single waste fraction X. For two different waste input variants, the auxiliary materials and energy consumed by the process and the residual waste, emissions and useful products leaving the process are calculated with the process model. The waste input of Variant (1) consists of 1000 kg waste with average composition including x kg of the waste fraction X. In Variant (2), the treatment process is calculated with an input of (1000-x) kg waste with average composition but without fraction X. The difference formed between the results of the process calculation for Variant (1) and the results of the calculation for Variant (2) gives the effects of the treatment of x kg of the waste fraction X in the disposal process. The derived results are valid under the condition that the process could be run with the same process parameters with and without the removal of fraction X from the average input. This presupposes fraction X being small. It has to be pointed out, that this approach is an allocation method. It does not describe the effect of changing the waste composition in an existing incineration plant.

3 Municipal Waste Incineration Model

Modelling the incineration process aimed at creating a tool for calculating the environmental impacts connected with the treatment of waste input of a defined composition in a municipal waste incineration process. The model assumes the technical state of the art for modern municipal waste incineration plants in Germany.

The system boundary of the unit process waste incineration with energy recovery comprises the steam generator, including the furnace body, the steam utilization and the flue gas purification plant. The process structure as well as the entering material and energy flows that cross the system boundary are shown in **Figure 3**.

- **Input streams** to the system are waste input, combustion air, auxiliary materials and energy for flue gas cleaning.
- **Output streams** leaving the system as solid materials are grate ash and boiler ash from the furnace and the residues from flue gas cleaning (filter dust, heavy metal sludge, gypsum, contaminated activated coke). The emissions to the atmosphere are contained in the clean gas coming from the flue gas purification. A part of the energy produced in the waste incinerator is extracted to produce grid power and district or process heat. There is no waste water leaving the system boundaries since the effluent from the scrubber is evaporated in a spray dryer by using the heat from the raw gas (→ *Fig. 7, p. 52*).

For the calculation the system is divided in the three subsystems steam generator, flue gas purification and steam utilization. The subsystems of the steam generator and the flue gas purification are coupled by the raw gas stream emerging from the steam generator. The subsystems of the steam generator and the steam utilization are linked by the water/steam circuit. The modular modelling allows a change of individual parts of this model. For example in case of a change of emission standards/stipulations another flue gas purification system can be used in the model.

3.1 Steam generator

The subsystem steam generator (→ *Fig. 4*) consists of grate firing and a heat recovery system (evaporator, superheater, economizer) and regenerative combustion air preheater. The

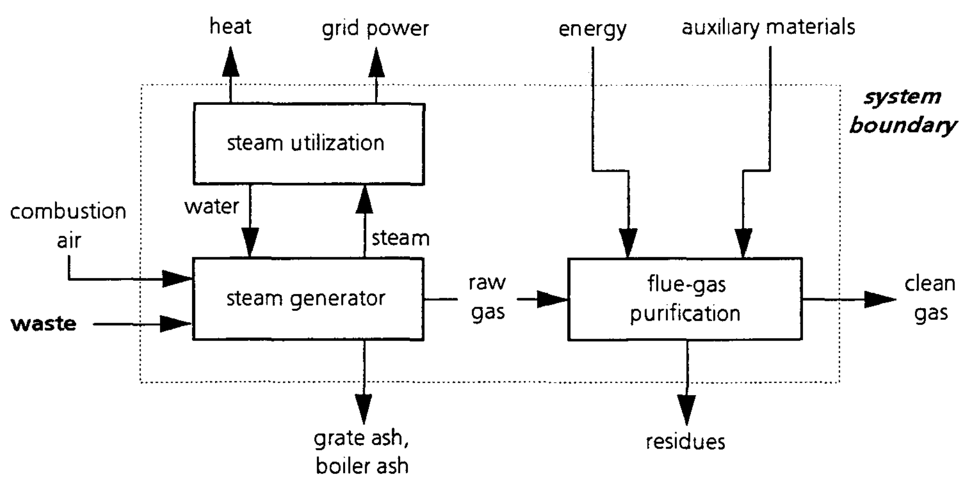

Fig. 3: Input/output flows and system boundary for the unit process waste incineration

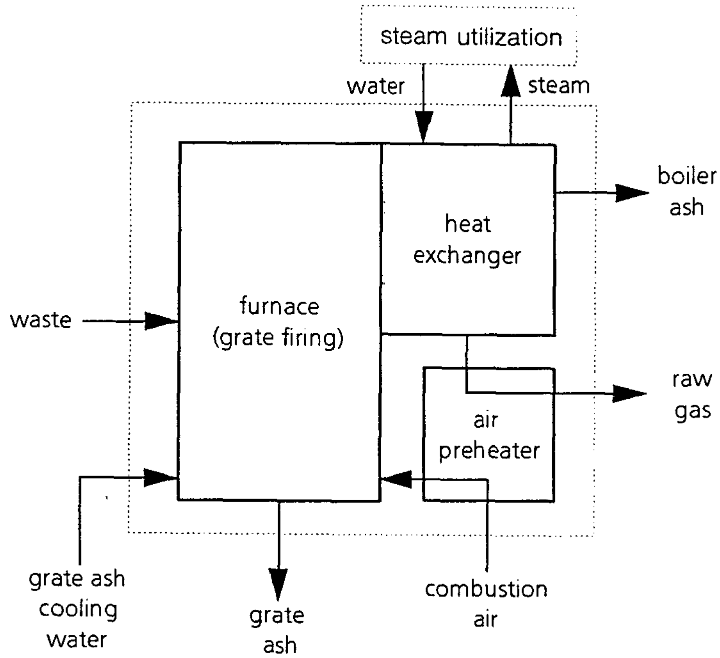

Fig. 4: Steam generator of waste incinerator with grate firing

steam generated has a pressure of 40 bar and a temperature of 400°C. The input streams to the subsystem are waste, air of combustion, grate ash cooling water and water (from steam utilization). The output streams are grate ash, boiler ash, steam (for steam utilization) and raw gas (for flue gas purification).

3.1.1 Mass balance

For the calculation of the mass balance of the combustion process, all input components of the furnace are split into their chemical composition (for an example see case study below, **Table** 4 (p. 53) and 5 (p. 53). The total input, accordingly, consists of the chemical elements C, H, N, O, S, Cl and F together with the moisture and the mineral fraction including heavy metals. Input flows entering the combustion process are waste input and combustion air. For the specified input composition the stoichiometric air requirement for the oxidation of the input substances is calculated first. With this and the air excess λ ($\lambda \approx 1.6 - 2.0$) specified for the combustion process the combustion air input and the amount and composition of the raw gas are calculated.

The output flows of the combustion process are raw gas, grate ash and boiler ash. The mineral fraction of the waste input is leaving the combustion system as solid materials with the grate ash, the boiler ash and the filter dust contained in the raw gas (→ *Fig. 5*). The distribution of these solids among the output flows is calculated due to transfer coefficients examined at the Würzburg MSW incinerator [3,4] and cross-checked with literature data.

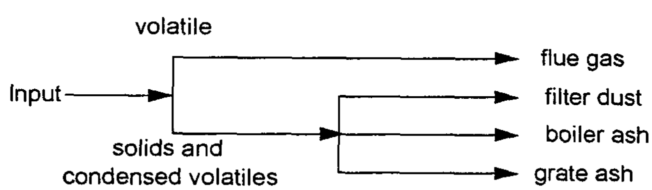

Fig. 5: Emission paths of the output flows from the combustion process

Table 1: Transfer coefficients for heavy metals in grate firing; evaluation of experimental data examined at the Würzburg MSWI [5]

Path	As	Cd	Co	Cr	Cu	Hg	Mn
Flue gas	0.2%	16.2%	0.3%	2.8%	0.2%	92.8%	0.2%
Filter dust	5.5%	56.2%	3.8%	4.3%	2.6%	0.8%	8.0%
Boiler ash	2.1%	1.4%	2.1%	2.0%	0.3%	0.4%	1.5%
Grate ash	92.3%	26.2%	93.8%	90.9%	96.9%	6.0%	90.3%

Path	Ni	Pb	Sb	Sn	Tl	V	Zn
Flue gas	1.7%	20.1%	2.9%	11.3%	0.00%	0.1%	12.1%
Filter dust	2.8%	14.4%	33.8%	26.5%	70.2%	9.0%	22.8%
Boiler ash	1.2%	0.7%	1.2%	1.4%	0.6%	2.0%	1.4%
Grate ash	94.3%	64.8%	62.1%	60.8%	29.2%	88.9%	63.7%

The amount and composition of the raw gas stream leaving the combustion process is calculated with the following approaches:

- The emissions CO_2, H_2O, N_2 and O_2 are calculated on the basis of the oxidation of the input substances.
- The emissions NO_X, CO, TOC and PCDD/F are assigned due to the amount of the flue gas volume. The data for average concentrations of this components in the raw gas from the waste incineration are derived from literature [5,6,7] and from incineration tests [3,4].
- The output flows of heavy metals (Hg, Cd, Tl and other heavy metals) are leaving the combustion system according to their volatility with the flue gas or condensed on particles of the solid output paths (→ *Fig 5*). The distribution of the heavy metals among the different output streams is calculated on the basis of transfer coefficients examined at the Würzburg MSW incinerator [3,4] (→ *Table 1*).
- The acid-forming input substances S, Cl and F are partly neutralized by basic ash components. The distribution of this input components to salts which are leaving the system with the solid output streams and to the gaseous emissions SO_2, HCl and HF contained in the flue gas are calculated on the basis of literature data [8].

3.1.2 Energy balance

For the energy balance around the furnace the calorific value H_U of the waste fuel is calculated from the elementary composition with the formula according to Boie [9] (m_i = mass proportion of component i on the total waste input in [kg/kg]; C = carbon, H = hydrogen, S = sulfur, N = nitrogen, O = oxygen, W = water):

$$H_U = 34.8\ m_C + 93.9\ m_H + 10.5\ m_S + 6.3\ m_N - 10.8\ m_O - 2.54\ m_W\ [\mathrm{MJ/kg}]$$

Energy losses taken into account are

- exhaust gas loss (approx. 15%, calculated depending on the temperature (≈ 200 - 220°C) of the raw gas after heat exchange),
- heat losses due to the enthalpy and the uncombusted components in the grate ash, boiler ash and filter dust (approx. 1%) and
- radiation and conduction losses (approx. 3%).

The total energy transferred to the water or steam in the steam generator is the energy input given by the calorific value and the mass of waste diminuished by the documented losses.

3.2 Steam utilization

The steam utilization (→ *Fig. 6*) comprises

- reducing the pressure of the fresh steam in the turbine to generate electric power,
- collecting useful heat,
- condensation of excess steam by means of an air condenser,
- conveying the condensate by means of feed pumps to system pressure.

Some of the energy contained in the fresh steam from the steam generator can be converted into electric power and some can be used for heating. The rest is dissipated by the cooling water and emitted to the environment as waste heat. The waste incinerator in the model provides steam with a quality of 40 bar/400°C. The overheated fresh steam is reduced in the turbine to steam-circuit pressure of at least 4 bar to permit heat export. During pressure reduction, 17% of the energy contained in the steam can be converted to electric power with an average turbine and generator efficiency [10]. The proportion of exported heat is assumed to be 20%, based on the amount of energy in the steam coming from the turbine (as practised, for example, in the waste incinerator in Würzburg). The rest of the energy contained in the steam must be dissipated by cooling water or by means of an air condenser (assumed in the model).

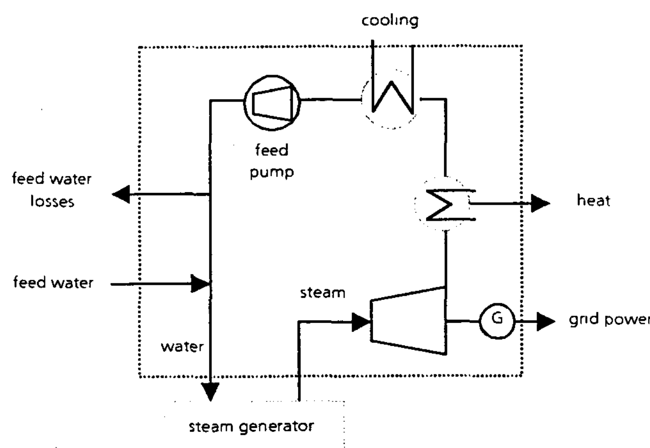

Fig. 6: Steam utilization

3.3 Flue gas purification

In Germany, the concentration limits for emissions to the air resulting from waste incinerators are regulated by a federal regulation laid down in the 17th BImSchV [11]. To ensure the keeping of the prescribed limits incineration plants must be equipped with a flue gas purification plant consisting of a filter system for dust separation, a scrubber for the removal of acid gases, a denitrogenation unit and a dioxin reduction system. Because of the large variety of flue gas purification systems applied in waste incinerators a representative modelling was not practicable.

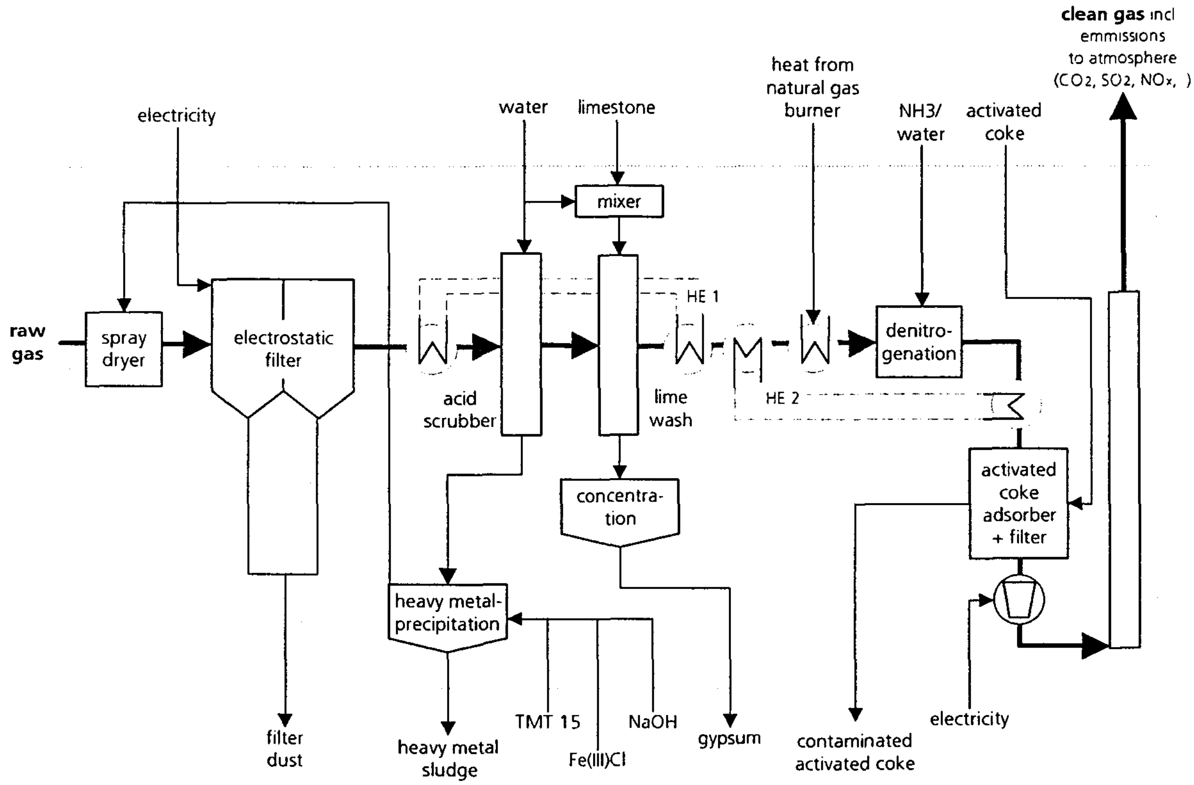

Fig. 7: Flue gas purification after waste incineration

The flue gas purification technology provided for the model as shown in Figure 7 represents the state of the art. It includes dust removal in an electrostatic precipitator, 2-stage gas scrubbing, selective catalytic reduction (SCR) of nitrogen oxides and finally an entrained bed adsorber. A suction fan for conveying the flue gases is arranged upstream of the flue.

After effluent treatment with removal of solids, the water from acid scrubbing and lime washing is conveyed to the spray dryer, where it is evaporated. Subsequently, the solids are separated in the electrostatic filter.

For flue gas reheating, two regenerative heat exchangers and a natural gas heated auxiliary burner are interposed between the electrostatic filter and gas scrubber (HE1) or gas scrubber and the denitrogenation unit (HE2). In the first regenerative heat exchanger, the heat coming from the flue gas downstream of the electrostatic filter is transferred to the flue gas emerging from the gas scrubber. The heat contained in the flue gas after the denitrogenation stage is utilized in the second heat exchanger for further heating of the flue gas. The amount of heat needed to adjust the denitrogenation working temperature (320°C) is provided by a natural gas fired auxiliary burner.

The input for the calculation of the flue gas purification is the raw gas coming from the combustion process with the composition and the condition as calculated in the steam generator subsystem. For the units of the flue gas purification plant, the consumption of auxiliary materials, the output flows and the separation efficiency for the single flue gas components are calculated by means of process models and empirical data derived from literature [12,13,14,15,16, 17,18,19,20,21].

The concentrations of harmful substances in the clean gas after having passed the activated coke filter are no longer depending on the composition of the input to the waste incineration process. For this reason measured data are used to describe the clean gas composition. Typical values measured at waste incinerators with the same flue gas purification system as described above are given in Table 2 and 3. In accordance with the 17[th] BImSchV, the figures are based on m^3_N dry flue gas with an O_2 content of 11% (v/v). The specific emissions assigned to the waste input are calculated by multiplication of the values given in the tables with the volume of the clean gas derived from the incineration of the waste.

Table 2: Emissions in clean gas downstream of activated coke filter. Values measured at the waste incinerator in Burgkirchen [22]

Dust	2	mg/m^3_N
NO_x	60	mg/m^3_N
SO_2	1	mg/m^3_N
HCl	1	mg/m^3_N
HF	0.05	mg/m^3_N
PCDD/F	0.02	ng/m^3_NTE

Table 3: Heavy metal concentrations in clean gas downstream of activated coke filter. Measured values from combustion experiments [23]

metal	concentration	
Hg	0.001	mg/m^3_N
Cd	0.005	mg/m^3_N
As	0.001	mg/m^3_N
Co	0.010	mg/m^3_N
Cr	0.0177	mg/m^3_N
Cu	0.010	mg/m^3_N
Mn	0.010	mg/m^3_N
Ni	0.010	mg/m^3_N
Pb	0.020	mg/m^3_N
Sb	0.001	mg/m^3_N
Se	0.001	mg/m^3_N
Sn	0.050	mg/m^3_N
Te	0.001	mg/m^3_N
V	0.005	mg/m^3_N
Σ_{HM} 1)	0.1367	mg/m^3_N

1) total parameter Σ_i heavy metals (i = As, Co, Cr, Cu, Mn, Ni, Pb, Sb, Se, Sn, Te, V)

4 Input/Output Flows for the Incineration of 1 kg Plastic Waste (Technical Articles)

The following example should demonstrate how the calculation of the incineration of a single waste component in a municipal waste incineration plant is put into practice. The special waste component studied in the example is the "technical article" fraction of the post-consumer plastics waste. This fraction represents the plastics portion coming from technical consumer goods. The proportion of this fraction on the total plastic waste is about 10%, the elementary composition is given in **Table 4** for the main input components and **Table 5** for the heavy metals according to the results of a survey conducted by APME [24]. **Table 4** and **5** show also the elementary composition of an example of an average domestic waste consisting of the input fractions organic waste, paper, metals, plastics (including "technical articles"), glass and others according to the results of a survey conducted in the city and the county of Würzburg in 1993 [25].

As mentioned before, the direct calculation of a multi-input process for single components can be misleading if there is no linear correlation occurring in the process model. In the waste incineration process internal material and energy recycling streams occur in the flue gas purification with the waste water from the acid scrubber and with the regenerative heat exchangers (→ *see Fig. 7*). The waste water from the acid scrubber is neutralized and after separation of the insoluble components (heavy metals) recycled to the spray dryer upstream of the electrostatic precipitator. The effluent evaporates as it enters the spray dryer, with the heat of evaporation being supplied by the hot flue gas and the chloride salts concentrated in the spray dryer are extracted in the electrostatic filter. For a waste input with a high proportion of chloride like the "technical article" fraction in our example a very high amount of scrubbing water is needed and the heat from the flue gas will not be enough for the evaporation of the effluent in the spray dryer. This will lead to a deficit in the energy balance. In reality the total input in a municipal waste incinerator will never exceed a chloride content of 2% and the heat of the flue gas will always be sufficient for the evaporation of the effluent.

Table 6 shows the input/output sides for the treatment of 1000 kg of the plastics waste fraction "technical articles" in the municipal waste incinerator calculated according to the method described above. The process model of the incineration was first calculated for the input variant (1) which was 990 kg domestic waste and 10 kg of the "technical article" fraction (the "technical article" fraction contributes 10% to the plastic waste fraction which has a 10% share in the total domestic waste). The input/output tables for 1000 kg of the "technical articles" fraction were determined by forming the difference with the results of the process model with an input of 990 kg domestic waste and multiplying this by 100.

For a comparison, **Table 7** shows the results of the calculation of the process model with an input of 1000 kg domestic waste of average composition. A comparison of results shows that the emissions and the products are more or less proportional depending on the calorific value of the input material. Looking at the results from the incineration of the "technical articles", the high amount of process water and filter ash are conspicuous.

Table 4: Calorific value and elementary composition of main input components for domestic waste (example composition) and the plastic waste fraction "technical articles"

	Calorific value	H_2O	Minerals	C	H	N	O	S	Cl	F
Domestic waste	11.02 [MJ/kg]	28.2%	23.2%	27.8%	3.8%	1.2%	14.7%	0.2%	1.0%	0.02%
Technical articles	33.44 [MJ/kg]	0.5%	1.8%	68.5%	11.0%	4.5%	9.1%	0.1%	4.7%	0.02%

Table 5: Heavy metal content of input fractions (mg/kg input)

[mg/kg]	As	Cd	Co	Cr	Cu	Hg	Mn	Ni	Pb	Sb	Se	Sn	Te	V
Domestic waste	3.4	4.3	9.3	248	335	2.3	152	61.5	356	4.9	0.0	0.5	0.0	16.8
Technical articles	0.4	688	116	75.6	27.9	9.0	3.0	13.9	3063	121	62.7	9.0	0.5	2.0

Table 6: Input/output balance for the treatment of 1000 kg of plastics waste fraction "technical articles" in the municipal waste incineration

Input		Output	
Waste	**1000 kg**	**Emissions**	
		CO_2 in clean gas	2509 kg
Auxiliary materials		H_2O in clean gas	3359 kg
Air (moist)	20451 kg	O_2 in clean gas	2084 kg
Process water	2115 kg	N_2 in clean gas	15522 kg
Ash cooling water	3.09 kg	No_x in clean	1029 g
Limestone	1.45 kg	SO_2 in clean gas	17.1 g
NH_4 (25%)	15.2 kg	HCl in clean gas	17.1 g
NaOH (50%)	82.4 kg	HF in clean gas	0.86 g
Activated coke	2.40 kg	NH_3 in clean gas	23.5 g
Fe(III)Cl	41.9 g	Dust in clean gas	34.3 g
TMT15	104.7 ml	TOC in clean gas	34.3 g
Boiler feed water	0.03 m³	CO in clean gas	300 g
		PCDD/F in clean gas	0.32 µg TE
Auxiliary energy		Hg in clean gas	0.02 g
Heat from natural gas	852 MJ	Cd in clean gas	0.09 g
Grid power	372 kWh	HM in clean gas	2.31 g
		Residues	
		Filter dust	68.5 kg
		Boiler ash	0.45 kg
		Bed ash	22.4 kg
		Act. coke (contam.)	2.49 kg
		Heavy metal sludge	0.75 kg
		Gypsum	2.16 kg
		Boiler feed water loss	0.03 m³
		Products	
		Electricity	1309 kWh
		Heat	4713 MJ

Table 7: Input/output balance for the treatment of 1000 kg of domestic waste of an average composition (as shown in Table 4 and 5) in the municipal waste incineration

Input		Output	
Waste	**1000 kg**	**Emissions**	
		CO_2 in clean gas	1018 kg
Auxiliary materials		H_2O in clean gas	1184 kg
Air (moist)	7012 kg	O_2 in clean gas	715 kg
Process water	464 kg	N_2 in clean gas	5322 kg
Ash cooling water	39.29 kg	No_x in clean	362 g
Limestone	2.02 kg	SO_2 in clean gas	6.04 g
NH_3 (25%)	5.35 kg	HCl in clean gas	6.04 g
NaOH (50%)	17.8 kg	HF in clean gas	0.30 g
Activated coke	0.85 kg	NH_3 in clean gas	8.25 g
Fe(III)Cl	9.03 g	Dust in clean gas	12.1 g
TMT15	22.6 ml	TOC in clean gas	12.1 g
Boiler feed water	0.01 m³	CO in clean gas	105.7 g
		PCDD/F in clean gas	0.11 µg TE
Auxiliary energy		Hg in clean gas	0.01 g
Heat from natural gas	293 MJ	Cd in clean gas	0.03 g
Grid power	123 kWh	HM in clean gas	0.81 g
		Residues	
		Filter dust	33.2 kg
		Boiler ash	4.67 kg
		Bed ash	233 kg
		Act. coke (contam.)	0.88 kg
		Heavy metal sludge	0.22 kg
		Gypsum	3.00 kg
		Boiler feed water loss	0.01 m³
		Products	
		Electricity	418 kWh
		Heat	1506 MJ

The over-proportional increase in process water consumption and filter ash output is caused by the high chloride content of the input material. Process water is used to separate the hydrochloric acid formed during chloride combustion and the increase of dust precipitated in the filter results from the chloride salts coming from the spray dryer.

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Part II: Sanitary Landfill – Waste Treatment in Product Specific Life Cycle Inventories

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The final disposal of waste in sanitary landfills generates environmental impacts in the form of gaseous emissions and effluents in the seepage water. In product specific Life Cycle Assessments, these environmental impacts resulting from the disposal of the product under study frequently have a strong influence on the overall results. The Sanitary Landfill (SL), like the Municipal Solid Waste Incineration (MSWI), is a complex system with a large variety of different types of waste with varying input composition. A direct determination of the environmental impacts resulting from the landfilling of a single input component, e.g. by measurements, is not possible. The model approach described in this paper shows an operationalized concept for the allocation of the environmental effects caused by the landfill process to special input components. The calculation of the landfill emissions in the model is based on the emission spectrum (landfill gas and seepage water) of an average-sized landfill in Germany and the elementary composition of the single waste fraction under consideration. The resulting reactor landfill module comprises an average split for diffuse and captured landfill emissions, the use of captured landfill gases in a gas engine and a cleaning of captured seepage water in a waste water treatment plant. A short case study demonstrates the calculation of the effects of landfilling of a defined waste fraction (bottle fraction in post-consumer, plastic waste).